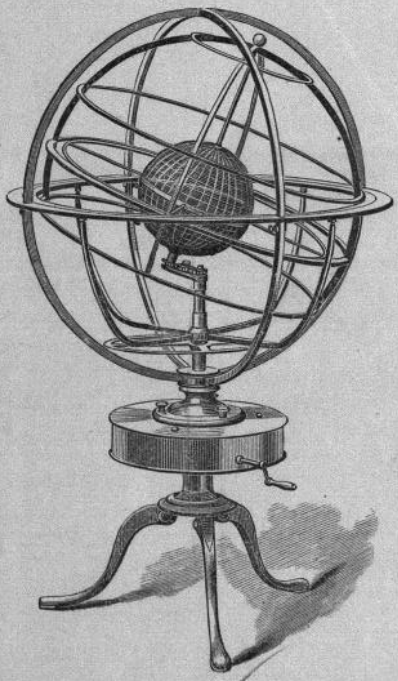
SYNOPSIS OF PRECESSION,

WITH THE NEW

PRECESSION APPARATUS.



By Prof. JAMES BUSHEE, A. M.

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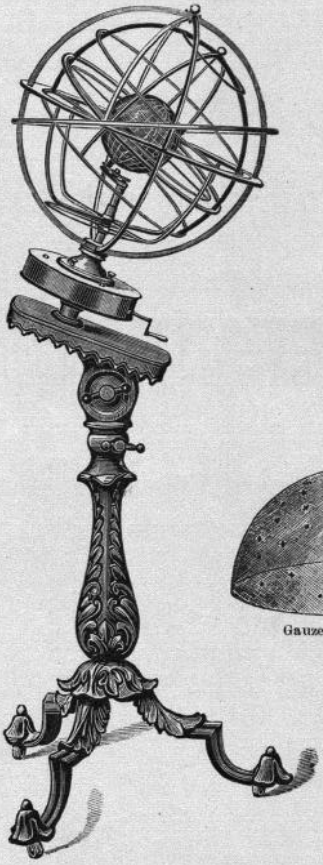

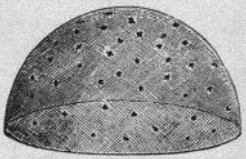

Gauze Hemisphere.

Bushee's Precession Apparatus with Adjustable Stand.

For Description see last page.

Precession of the Equinoxes.

A SYNOPSIS OF THE LEADING PRINCIPLES

IN CONNECTION WITH THE PHENOMENA OF

THE "ANNUS MAGNUS" OR "GREAT YEAR,"

WITH THE DESCRIPTION OF A NEW

PRECESSION APPARATUS

For Illustrating these Phenomena

IN THEIR SPECIAL RELATION TO THE CLIMATAL CHANGES OF OUR GLOBE, WHICH MAY RESULT IN A "GREAT ICE AGE," OR "GLACIAL EPOCH."

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Introductory Remarks.

Object and Necessity.—Every one, engaged in teaching the Elements of Astronomy, will doubtless acknowledge the difficulties experienced in his attempts to impart to the mind of the student a clear and definite idea of the Precession of the Equinoxes and its various effects.

The cause and effects of that grand movement of the earth producing what is termed "Precession of the Equinoxes" are, as generally accepted, among the most difficult branches of Physical Astronomy.

It is true, various methods of illustration have been devised, with the view of conveying more definite notions upon the subject.

For example, besides the various diagrams usually given in the books, reference has frequently been made to the common "spinning top,"—and to the motion of the "Gyroscope," or some of its modifications.

In some instances the motion simply of the equinoxes has been shown, while complicated with other motions of the earth, in some forms of the Orrery or "Season Machine."

Passing over the respective merits and defects of these methods, it seems to me they all fail to meet the reasonable demands of instruction, while some perhaps tend rather to confuse than to elucidate the points involved.

During the writer's experience in teaching elementary Astronomy, he has long felt the necessity of more complete and satisfactory means of aiding the student's conceptions in gaining a more thorough knowledge of Precession, which embraces some of the noblest and most practical truths of the science.

The apparatus now presented to the public is an attempt to supply this necessity, and whatever merit or utility it may possess has grown out of a desire to awaken a deeper and more general interest in the subject.

Glacial Epoch due indirectly to Precession.—The appearance of a New Instrument to illustrate the Precession of the Equinoxes may be considered timely, just now, and a still greater importance attached to the study of the subject, from the fact that some eminent Geologists have recently referred the climatal changes which may produce a Glacial epoch to the *indirect* influence of Precession combined with a *high* eccentricity of the earth's orbit.

This, to say the least, has been an additional incentive to bring into play all the means in our power to simplify the subject and bring it within the reach of popular instruction.

In order to present a more comprehensive view of the scope and utility of the *New Apparatus* from an educational stand-point, it was thought best to precede the *description* of it by a connected outline of the leading principles of Precession,—the phenomena of the "*Great Year*" and their bearing on secular *changes of climate*—all of which the Instrument is especially designed to illustrate.

General Phenomena of Precession.

Great Precession Period.

What constitutes Precession?—No student of Astronomy will ever cease to cherish an interest in the subject after having been once made to comprehend and appreciate that grand *long period* movement of the earth, by which, under the gravitating forces of the sun, moon and planets, poised in empty space, it is made to bow and rock and roll like a ship on the ocean wave until it has finally made one *great bow*, all the while with little "noddings," (nutation,) or rather until it has completed a mighty wabble requiring a period of nearly 26,000 years to accomplish. This motion of the earth causes the celestial equator,—which partakes of the same motion,—to cut the stationary ecliptic a little sooner every year than it did the preceding year, producing a slow retrograde motion of these points which is termed *Precession of the Equinoxes.*

Effects of Precession in changing the position of the Stars.—At the close of this grand period the equinoxes will have fallen backward in order of the signs through the entire circle of the ecliptic, and the north Celestial Pole will have swept around the northern pole of the ecliptic in a circle of 47° in diameter and of course the south pole of the heavens made a similar circle about the southern pole of the ecliptic,—while the Longitude, Right Ascension and Declination of all the stars will have passed through corresponding changes.

The greatest apparent change.—The maximum or greatest apparent amount of displacement having been attained after the lapse of about 12,900 years, when the north pole, having left the present pole star 47° behind will now claim Lyra as a guiding star which crowns that beautiful little constellation "The Harp," and which is now nearly in the zenith during our present summer even-

ings. Our Spring or the vernal equinox will then commence in the constellation Leo instead of Pisces,—each season corresponding to the opposite of the present,—that is, the Spring will correspond to our Autumn, and the Summer to our Winter, and the beautiful stars and constellations that now adorn our winter evening skies will be visible but in part, and that too only in our summer evenings, while others will disappear entirely from view, their places being supplied perhaps by those of inferior magnitude as unwelcome intruders.

The brilliant *Capella*, for instance, that marks our zenith in a January sky, will be transferred 47° south—very nearly to the Celestial Equator, while dim Polaris, our present pole-star, in the tail of the *Little Bear*, will take its place almost exactly in the zenith of our latitude—Worcester, Mass.

Our zenith sky then is no longer brilliant with a winter *Capella* and a summer *Lyra*.

Procyon, Aldebaran and the Pleiades will then troupe their way through the southern hemisphere instead of the northern, the splendors of Orion will be lost in the dim horizon, and *Sirius*, the pride of "*Canis Major*," will never blaze above.

Ursa Minor and *Ursa Major* will be elevated to the very *Mid Heaven* far removed from *Perpetual Apparition*,—will rise and set, tracking the celestial vault in great circles, as *Canis Minor* and *Canis Major* now do,—*Ursa Minor* leading the way and *Ursa Major* following after bearing the *Dipper* on his way with the familiar *Pointers*, *Dubhe* and *Merak*, which have so often guided the wandering eye to the pole-star, but which have long since lost their significance in the depths of the past.

Verily there will be *apparently* a "*New Heavens*" and in some respects *really a* "*New Earth*."

But as time rolls on the north pole now begins slowly to approach its former position, the equinoxes have reached the turning point and are now shaping their course homeward;—the apparent displacement of the constellations seems gradually to diminish, and when 127 centuries more have glided away, the pole will have resumed its present place near the star "*Polaris*,"—the equinoxes will have reached their starting goal, while the stars and constella-

tions, after having completed their long cycle of revolutions, will all be found marshaled into the same relative position,—so far as precession is concerned—which they occupied 26,000 years before, when they will again resume their "*ceaseless* round."

During this period, which may be termed the *great precession period*, the stars pass through every possible degree of longitude and of right ascension from 0° to 360°.

The declination also is constantly oscillating within certain limits of greater or less extent, now increasing, now diminishing; sometime zero or on the equator, then north, then south.

Since the celestial equator is always perpendicular to the axis of the heavens, it must change its position, relative to the stars, as the equinoxes fall backward, hence every star or point in the heavens must be subject to a change in declination, with the exception of the poles of the ecliptic. These points being always 23° 28' from the poles of the heavens, and in the *axis* of that motion of the earth which produces precession, they will always retain the same relative position with respect to every point in the equator; having 66½ degrees of declination.

Latitude however being reckoned from a *fixed* circle,—the ecliptic—cannot change by Precession.

"Annus Magnus," or Great Year.

Length and changes of Great Year.—Besides the grand *Precession Period* of 25,800 years, involving numerous changes in the apparent motions and positions of the stars, as just described, there is another *long period* intimately connected with this, extending through about 21,000 years and embracing a series of phenomena of special interest regarding the seasons and climate.

The long period changes which the earth undergoes in relation to the sun, requiring thousands of years to accomplish, are as precise and regular in their recurrence as those more familiar, annual or diurnal changes, which are brought about in a few hours, or a few months; and, in many respects, bear a striking analogy to our yearly alternation of seasons; hence the period in which their cycle is completed may be aptly termed *The Great Year*, of which

our annual changes of seasons may be taken as a miniature representative.

Some of these changes will now be briefly noticed.

Sun's distance and intensity of heat variable.—As the earth's orbit is eliptical the distance of the sun is constantly changing, and since the intensity of light and heat varies inversely as the square of the distance, it follows that the degree of heat received from the sun at different times is also variable. Furthermore the same distance and the intensity of heat depending on that distance does not correspond to any particular season. Sometimes the earth is nearer the sun in our Summer, sometimes in Winter, the reverse being the case in the opposite hemisphere. It so happens, that our winters occur, at present, very nearly in perihelion or nearest point to the sun, and our summers in aphelion, most distant from the sun. This however will not always be the case. The condition of things will slowly change, and in the course of 100 centuries the order will be completely reversed, that is, our summers will take place in perihelion and winters in aphelion.

What constitutes the Great Year.—Since the equinoxes fall back on the signs of the ecliptic at the rate of 50.24" annually, or one degree in 71.6 years, the whole circle of the ecliptic would be made,—provided the motion is uniform,—in 25,800 years,—the grand "*Precession Period*,"—and since the perihelion and aphelion points or the earth's apsides have a very slow motion in the opposite direction or in direct order of the signs, at the rate of 11.29" annually, these points would separate or approach each other at the rate of 61.53" of arc, yearly, and consequently would be in the same relative position once in every 21,000 years.* This constitutes *The "Great Year,"* in which the earth passes through a definite series of changes in regard to the seasons. The Great Year may be divided into four seasons or four *Quarterly Periods* depending upon four remarkable positions of the Apsides and Equinoxes.

First Quarterly Period.—*Position of Perihelion, Commencement of the Great Year.*—In order to indicate a little

*Or as often as 61.53" are contained in the number of seconds in 360°=1296000" ÷61.50"=21,000 nearly.

more definitely what takes place during the *great year*, let us suppose the perihelion to coincide with our Winter Solstice and of course the aphelion with our Summer Solstice—which was found by La Place to be the case in the year of our Lord 1250—which will be a convenient point to commence the Great Year. In this position, the earth is the nearest possible to the sun in mid-winter and the greatest possible distance, with its present eccentricity, in mid-summer, the difference in distance being about 3,000,000 of miles. Again, the difference in the length of opposite seasons is the greatest possible, amounting to about 8 days; that is, the time of passage from the autumnal equinox to the vernal is found to be 8 days less than the time elapsed from the vernal to the autumnal equinox. But as time passes on, the condition of things slowly changes;—the mid-winter distance of the sun is gradually increasing while the mid-summer distance and the difference in length of seasons are diminishing.

After 626 years have elapsed from 1250 we are brought up to the present date, 1876, yet so small has been the amount of change since the great year commenced, that it would be quite imperceptible except by the most experienced and skillful observers with the best instruments.

Second Quarterly Period.—In the course of fifty centuries, however, or 5,000 years after 1250, that is, in the year of our Lord 6250, or thereabouts, another important period in the great year will take place, the apsides will coincide with the line of equinoxes, the perihelion with the vernal, and aphelion with the autumnal equinox, the difference of 8 days in the seasons will vanish, the time of passing from vernal to autumnal equinox being the same as that from autumnal to vernal, and the 3,000,000 miles difference in the extreme distances of the sun will also disappear; the distance in mid-summer being the same as in mid-winter and nearly equal to the mean distance.

Third Period reached.—Now the two hemispheres change their relation to the sun; our northern hemisphere will gradually approach its summer perihelion, reaching that point in about 5,250 years more, when the earth will be nearest the sun in our mid-summer and farthest distant in mid-winter, while just the oppo-

site will take place in the southern hemisphere. The northern having short hot summers and long cold winters;—the southern, short winters and long summers.

In 10,500 years then from 1250, or in the year of our Lord 11,250, the seasons will all be reversed and half of the *great year* completed. This constitutes a *third marked period* in the great year.

This state of things will remain nearly the same for several centuries, or without perceptible change, but the middle of the great year is now passed and the earth is shaping its journey homeward. During the next 10,500 years the same series of phenomena, as just described, will take place but in opposite order.

Fourth Period.—In about the middle of this half year, the line of apsides will again coincide with the line of equinoxes. In this case however, the vernal equinox will correspond to aphelion, and the autumnal to perihelion, but the distance of the sun will be the same in summer as in winter in both hemispheres, and no difference in the length of seasons, as was the case 10,500 years before.

Finally, in 5,250 years more, the earth will return to its supposed starting point (in the year 1250), when the great year will be completed and the line of apsides and solstices again restored to their former position 21,000 years before, with perihelion in the winter solstice and aphelion in the summer solstice.

As there are four seasons annually, or rather four noticeable positions in reference to the equinoxes and solstices, affecting the temperature and the length of days and nights,—in the summer solstice, the greatest heat with the longest days and shortest nights, in the winter solstice the greatest cold with the shortest days and longest nights; at the equinoxes, an equality of day and night with a medium temperature;—so in the *Great Year*, as we have seen, there are four remarkable positions of the apsides and equinoxes, in two of which, the greatest variation of the sun's distance and the greatest difference in the length of the seasons take place, while in the other two positions the sun's distance is the same and the length of seasons the same.*

*Further reference to these positions will be made in connection with the description and use of the Instrument.

It should be noticed however, that the familiar changes of our seasons are entirely due to the inclination of the earth's axis combined with its annual motion, in relation to the apsides and equinoxes, while the changes of the *great year* are caused by the motion of the apsides and equinoxes themselves.

In consequence of the eccentricity of the earth's orbit, producing a difference of 3,000,000 of miles in the extremes of the sun's distance, the intensity of heat at perihelion must be far greater than in aphelion, but other causes tend to modify these extremes, so that the average temperature is not materially affected by a low eccentricity.

Eccentricity itself a variable element.—While Geometers have demonstrated that the major axis, the mean distance, and time of revolution are constant, they have equally proved the variability of the minor axis and eccentricity.

This fact, at first, created no little anxiety, for fear that an indefinite increase of eccentricity, however slow the change, might in time, as is the case of some of the asteroids and comets, carry the earth so far away from the sun as to entirely change the climate of our globe and finally destroy the present economy of the animal and vegetable kingdom.

The profound investigations of Lagrange and La Place, however, soon quieted these apprehensions, by proving that the variations of eccentricity were confined within certain moderate limits, beyond which they could never go.

The vibrations, however, from one extreme to another, require immense periods of time to accomplish—while numerous minor oscillations occur between them.

Limits of Eccentricity.—The eccentricity is now diminishing and will reach its inferior limit, according to Leverrier, in 23,980 years, when the orbit of the earth will be very nearly a circle.

Reckoning backward, it is found that the superior limit, or very nearly that, was attained 850,000 years ago, and farther still in the depths of the past, or about 2,500,000 years ago, another very high eccentricity was reached.

In both these cases, the difference of the extreme limits of the sun's distance, corresponding to such eccentricity, is over 13,000,000

of miles, instead of 3,000,000 as at present, while the difference in length of seasons amounts to 35 or 36 days, instead of 8 days.

Effects of a high Eccentricity on Climate.—Although it is generally allowed, as above stated, that eccentricity alone cannot affect the general climate, yet some eminent Geologists believe that *very high* eccentricities, combined with the effects of precession, as regards the phenomena of the *great year*, may *indirectly* effect such a change in climate as would be quite sufficient, not only to alter materially the character of the *Flora* and *Fauna* of the present, but to produce such extremes of heat and cold alternately in the northern and southern hemispheres during the *great year*, that a "Glacial Epoch" may ensue.

When Glacial and Inter-Glacial Epochs occur.—While he admits that a mere increase of eccentricity is not alone sufficient to change the climate materially, much less to produce a *glacial epoch*, Mr. Croll argues, and with much plausibility, at least,* that under high eccentricity, a variety of physical agents are brought into play, whose combined effect tend to produce a very great degree of cold in that hemisphere whose winters occur in aphelion, while the same causes operate to increase the heat nearly to the same degree in the opposite hemisphere whose winters are in perihelion.

According to this view, each hemisphere will be exposed alternately to these extremes of heat and cold for about 10,500 years, or half of the *great year* just described. The cold period may be termed the *winter* of the great year, and the hot period the *summer* of the great year, and any amount of snow and ice accumulated in either hemisphere during the great winter would be melted away during the great summer.

It is not however supposed that a glacial epoch will occur every *great year*, or once in every 21,000 years, neither is it supposed that no glacial period can occur except at the highest limit of eccentricity.

Effect of different Eccentricities on Climate.—The numerous physical agents, more directly effecting important changes in

*See "*Climate and Time in their Geological relations;—a theory of secular changes of the earth's climate by James Croll.—D. Appleton & Co., N. Y.*"*

climate are, according to Mr. Croll, brought into greater or less activity in proportion to the extent of eccentricity.

In a moderately high eccentricity therefore,—even considerably below the extreme,—if continued for a long time, through several consecutive *great years*, the combined effect of these agents may be so *cumulative*, under favorable circumstances, as to produce all the results of glacial action which past geological time has revealed, while the only effect of a low eccentricity, as exists at present, is to change the relative temperature of the two hemispheres, without strongly affecting the general climate; thus our seasons are now passing through the summer of the *great year*, and the seasons of the southern hemisphere, through the winter of the *great year*, and it is well known that the average temperature of our northern latitudes is much warmer than that of the southern hemisphere in the same latitudes,—that a much larger quantity of ice and snow prevails about the Antarctic regions than about the Arctic, and these facts accord with the theory in question.

The Theory of Mr. Croll accords with Observation.—This is not the place to discuss the merits of Mr. Croll's hypothesis in a Geological point of view. Our object is merely to notice its immediate connection with the *great year* and its general bearing upon the subject under consideration.

One remark, however, may be hazarded, that whatever weak points the theory may be supposed to contain, or whatever objections may be urged against the reasoning by which it is supported, it seems to account for the phenomena of the glacial and interglacial periods, better than any other hypothesis which has hitherto been advanced, and promises to afford some clue to the solution of a problem which has long puzzled Geologists,—a satisfactory explanation of those alternate long periods of heat and cold, even in high latitudes, whose actual existence must be admitted, in order to meet the demands of Geology. It will not probably be denied, that the hypothesis has the merit of harmonizing with many of the observed facts of Geology in a remarkable manner, and thus far, at least, it commends itself to favorable acceptance.*

*"Great Ice Age"—In its Relation to the Antiquity of Man.—Prof. James Geikie, F. R. S. E., F. G S.

When the theory first appeared 10 or 12 years ago, it received but little notice, but as the drift phenomena were more carefully studied and became better understood, it gradually grew in favor, and is now accepted by some eminent Geologists.

If indeed those great secular changes of climate, which are adequate to bring about a "*Glacial Epoch*," or "*Drift Period*," are found to be due to cosmical causes,—in fact are "*indirectly*" the results of Precession combined with the eccentricity of the earth's orbit, the fact will link the child Geology with its most remote Ancester, Astronomy, with still stronger bonds of unity, and dignify the study of that noble science, and especially the subject under consideration, with a higher interest and significance.

DESCRIPTION AND USE

OF THE

Precession Apparatus.

The instrument consists mainly of two concentric armillary spheres, or systems of circles mounted upon a proper stand for table, as seen in the cut, Fig. 1. The outer system of circles comprise the ecliptic, or apparent orbit of the sun, here represented horizontally, with four great meridian circles terminating in the poles of the same. This system of circles corresponds to the so called sphere of the fixed stars.

The inner and movable sphere of circles comprise the celestial equator, tropics, polar circles, and the equinoxial and solsticial colures. The small globe in the center represents the earth with its axis inclined $23\frac{1}{2}$ degrees to the axis of the ecliptic, and consequently the plane of the equator makes the same angle with the plane of the ecliptic, intersecting each other in opposite points, called Equinoxes.

The point which the sun passes about the 21st of March, is termed the Vernal Equinox,—the opposite point occupied by the sun about the 23d of September,—the Autumnal Equinox.

Fig. 1, Bushee's Precession Apparatus.

What motion is communicated to the Earth.—By a key connected with the simple mechanism enclosed in the cylindrical box below, motion may be given to the earth and to the inner system of circles about an axis coinciding with the axis of the ecliptic.

At the same time the direct axial motion of the earth is avoided by a system of wheel-work, precisely the same as that which preserves the parallelism of her axis in illustrating the "seasons."

All other motions then being designedly set aside, the subject is greatly simplified and that "rolling," "wabbling" movement which produces Precession more prominently brought out.

Earth in Center.—And since the subject of Precession deals with the stars and star distances, which are so immense that the earth's orbit, or the apparent path of the sun dwindles down to a mere point, the proper position of the earth, for convenience of illustration, is in the center of the great circles of the sphere, while the apparent place of the sun is correctly represented by a small brass ball on the ecliptic.

How the Signs differ from the Constellation of the Zodiac.—The ecliptic itself, as here represented, consists of two concentric circles, both of which are divided into 12 signs of 30 degrees each.

The outer circle representing the names and positions of the 12 Constellations of the Zodiac, while the inner circle bears the names of the 12 signs, and moves with the precession of the equinoxes, showing at once, the relative position of the Signs and Constellations of the same name.

It will be observed that the sign *Aries* now occupies the constellation *Pisces* and the sign *Taurus* the constellation Aries, and so on, each sign being 30° back or westward of the constellation of the same name, or what is the same thing, each constellation is 30° in advance of the sign of the same name.

About 2150 years ago, the vernal equinox, or the point Aries, doubtless coincided with the beginning of the constellation Aries, and so all through each sign, corresponding to the constellation which bears its name,—in fact, the signs and constellations were one and the same thing, but in consequence of Precession, the vernal equinox is constantly falling backward on the ecliptic changing the position of all the signs in regard to their respective constellations.

This motion creates the necessity of carefully distinguishing between the *signs* and the *constellations* of the same name; also, for clear illustration, the necessity of having two separate rings in the apparatus, named and divided in the manner already described.

The vernal equinox must always be in the beginning of the sign *Aries*, whatever constellation this point may occupy, since the time of the sun's passage from the vernal equinox to the same point again, constitutes what is called a tropical year, the basis of our division of civil time.

Illustrations.—All these facts may be clearly illustrated. Place the little brass ball representing the sun at the vernal equinox, or beginning of Aries, on the inner circle; turn the key slowly and observe what takes place. First, the little ball denoting the sun at the vernal equinox, the 21st of March, will be seen leaving the constellation Pisces in the outer circle and slowly moving backward along the constellation Aquarius,* while all the signs of the inner circle are making corresponding changes with the constellations of the outer circle, as may be seen at a glance.

Earth's wabbling motion shown.—Now place a small piece of paper upon the globe and mark its movements as you turn the key. The earth does not revolve on its axis, but the rolling, writhing motion, which alone causes Precession, is very noticeable.

Motions of the Poles.—At the same time the north pole has left its former position and is now tracing its "winding way" among the stars, in a circle 23½ degrees from the pole of the ecliptic, and since the center of motion passes through the center of the earth, the south celestial pole will describe a corresponding circle about the south pole of the ecliptic.

Finally, since the inner system of circles, connected with the earth, must move as the earth itself moves, and partake in general with the motion of the equinoxes, it will be noticed, at once, that, while these circles all retain their positions with respect to each other and move as a whole, they are all constantly changing their positions in various ways with respect to the outer circles or sphere of the fixed stars.

This may be well shown, by placing in *position* a wire gauze hemisphere (which accompanies the apparatus) over the circles, having arranged upon it some of the most prominent stars and constellations of this part ol the heavens.

*This denotes the motion of the equinox rather than that of the sun.

How the Phenomena of the Great Year is Illustrated.—In order to illustrate the *Great Year* already described, the elliptic orbit of the earth is placed below, on an independent arbor, which by a simple system of wheel-work, gives the apsides their proper motion, about 11.29" of arc annually, in direct order of the signs, or contrary to the motion of the equinoxes, and the *Great Year*, as has been explained, is produced by the relative motion of the apsides and equinoxes, by which the same points are brought together in about 21,000 years.

Now, in order the eye may catch at once the relative position of the apsides and equinoxes, a small circle, corresponding to the circle of signs with index, is placed just above the elliptic orbit of the earth, and on the same arbor that gives motion to the signs, showing at once, when the equinoxes coincide with the apsides, when with the tropics, when the four *remarkable periods* of the *Great Year*, already spoken of, take place,—when the long winters and the long summers occur, in either hemisphere, and when they are reversed,—when the glacial epoch must occur,—if it occur at all,—and in fact the seasons of the *Great Year* and all the phenomena of the grand period of 21,000 years, referred to under the head *Great Year*, may be as clearly brought out to the comprehension of the student as are the familiar facts relating to the four seasons of our year.

Further Illustration of its Use.

LATITUDE, LONGITUDE, RIGHT ASCENSION AND DECLINATION.

Importance of understanding in the outset the object and uses of the two systems of circles.—In order to study to advantage the mode of finding the position of the stars and the effects of Precession, it is necessary, first of all, for the student to make himself acquainted with the object and uses of the two systems of great circles which constitute the two concentric spheres represented in the figure.

Latitude and Longitude refer to the outer sphere of circles.—For instance, the circles of the outer sphere,—the ecliptic and its meridians, are used exclusively to determine latitude and longitude of the stars.

The distance reckoned eastward on the ecliptic through the entire circle, or 360°, from the meridian, passing through the vernal equinox, is called *Celestial Longitude.*

The distance north or south of the ecliptic measured on a meridian is termed *Celestial Latitude.*

Right Ascension and Declination.—It is, however, found more convenient generally to define the position of a heavenly body by reference to the great circles of the inner sphere, viz: the equinoxtial and its meridians, all of which move with the equinoxes.

The distance of a body measured on the equinoctial eastward from the meridian passing through the point Aries, is termed *Right Ascension.*

The distance reckoned on a meridian north or south of the equinoctial or celestial equator is called *Declination.*

Distinctive uses of the two Systems.—Celestial latitude and longitude then have reference to the outer or *Ecliptic System* of circles,—right ascension and declination to the *Equinoctial System,* and correspond to terrestrial latitude and longitude, since the celestial equator is simply the plane of the earth's equator extended to the heavens.

In order to obtain a clear idea of the distinction between longitude and right ascension,—also, between latitude and declination, the student should carefully observe the relative position of the great circles from which, and on which these distances are respectively measured, and to which *system* of circles they respectively belong.

Longitude and Right Ascension frequently confounded. Since longitude and right ascension are both reckoned eastward 360°, through the circumference of a great circle, and both are reckoned from meridians passing through the same point Aries or vernal equinox; the question is often asked:

Why then are they not the same thing? How do they differ?

A little attention to the position of the two systems of circles, as seen in the diagram, or the instrument, will at once make this point clear. As the equinoctial makes an angle of 23½ degrees with the ecliptic, the *prime* meridian of longitude makes the same angle with the *prime* meridian of right ascension, and hence these can only coincide at the point of intersection—the vernal equinox, —the only point having the same longitude and right ascension.

To illustrate this, bring the graduated movable meridian of longitude to the vernal equinox.

It is oblique to the prime meridian of right ascension, and any point in the latter, north of the ecliptic, will be in advance, in order of the signs, of a similar point in the former, and any point in the latter, *south* of the ecliptic, will be *back* of the former in order of signs. The two points in opposite latitudes, being on the same prime meridian, have no right ascension, while they have very different and opposite longitudes.

For another illustration,—let a star be represented on the prime meridian of longitude, at about 45° of latitude and call it *Alpha*. Place another on the prime meridian of right ascension, having about the same north declination and call this *Beta*. Now it will be noticed that *Alpha* has no longitude and *Beta* no right ascension, yet *Alpha* has a certain right ascension and *Beta* a certain longitude, and while the meridians of both pass through the same point Aries, the stars occupy very different positions and this shows the difference each star holds as to right ascension and longitude, and serves to illustrate the specific distinction of these terms.

Declination affected by Latitude.—If these stars be removed farther north on their respective meridians, it is plain the difference of longitude and right ascension will increase, if removed farther south it will decrease as the latitude is less and finally vanish at the equinox.

This shows the effect of latitude on right ascension, while it does not affect longitude.

Difference of Longitude and Right Ascension Determined.—Suppose the two stars to remain as at first, *Alpha* 45° north latitude and *Beta* 45° north declination. Slide the movable meridian along the sign Aries till it comes centrally over the star

Beta, and mark where it stands on the graduated circle of signs, about 19° from the first point of Aries. This is the longitude of *Beta*.

To find the Right Ascension of Alpha.—Slide the meridian a little farther along, till the star *Alpha* is brought centrally over the prime meridian of Right Ascension. It now stands about 24° on Aries, which is the difference of longitude and right ascension of *Alpha*, as if reckoned westward, but the true right ascension, as reckoned eastward, would be 360°—24°=336°.

The same result would be obtained by fixing prime meridian at vernal equinox and turning the key till the meridian of Right Ascension was brought centrally under *Alpha*. The vernal equinox stands on 6° in Aquarius in the *outer circle*, consequently it has passed through 24° of the same sign, showing, as before, the point of right ascension westward.

Summary—*Alpha*, longitude 0, Right Ascension 336°.
Beta, Right Ascension 0, longitude 19°.

All the stars then on the solsticial colure will have the same longitude and right ascension, which cannot take place in any other case, since this is the only circle that coincides with the meridians of the ecliptic system and cuts both the equator and ecliptic at right angles.

Effect of Precession on Longitude and Right Ascension. The effect of Precession, as regards the longitude and right ascension of the stars, may be finely illustrated, to a large class even, by placing the gauze hemisphere in *position*, through which the great circles of the sphere may be easily seen; noting the position of some prominent stars, both east and west of the prime meridians of longitude and right ascension; then turning the key, the prime meridians will be seen to move backward with the equinoxes, leaving the stars on the right or eastward and thus increasing their longitude and right ascension. At the same time these meridians are approaching the stars on the west, yet equally increasing their longitude and right ascension, for when a star comes to its prime meridian it has the greatest possible longitude and right ascension, or 360°, and at the same instant, nothing when it begins to increase to the right.

Effect of Precession on Declination.—A single illustration must suffice to show the *general effect of Precession on Declination.* Let a star be placed on the ecliptic at the Vernal Equinox. It has no latitude, because on the circle from which latitude is reckoned. It has no declination for a similar reason, as it is on the equator.

It has no longitude or right ascension, because it is on both prime meridians.

Now give the equinoxes their proper motion and mark the changes in declination through an entire revolution—during the great Equinoctial Period of 25,800 years.

While passing through the first three signs the declination will increase north reaching its greatest limits, $23\frac{1}{2}$ degrees, in about 6,500 years. During the next quarter of the great period the declination decreases in the same ratio, till the star comes again to the equator. The declination will now increase, reaching its maximum, $23\frac{1}{2}$ degrees south, in about 6,500 years more. It will then decrease for a like period, when the star will come to the starting point on the equator, having in the course of 25,800 years, crossed the equator twice, reached the greatest limits of north and south declination and made a *change* of declination of 47°.

All the stars north and south of the equator to the Polar circles are subject to the same amount of change in declination.

From the Polar circles to the poles the declination varies from 47° to 0° and the amount of change is always equal to twice the complement of declination or twice the polar distance, as may be seen at once by the instrument.

A great variety of interesting and instructive problems may be readily understood and solved by aid of the *Precession Apparatus.*

For Example.—Place the gauze hemisphere in position, turn the key and it may be seen at once what stars for ages to come will be pole stars, and what have been in ages past.

While the pole is moving from its present position to the nearest point of any particular star in the vicinity of the polar path, mark the number of degrees passed over on the ecliptic by the Vernal Equinox, and since the average precession amounts to 71.6 years for every degree, we have merely to multiply the degrees by this

number and we obtain the number of years that will elapse before that star will be the pole star. Thus it will be found that the pole will pass within about 3° of Alderamin, a prominent star in Cepheus, in about 5,800 years, though the star may be used as pole star ages before, and ages after the pole passes its nearest point.

Our pole star has been used as such for centuries, yet the pole will not reach its nearest point (within half a degree) in over 200 years, but the same polaris will retain the honor of its position for ages after the nearest point is passed.

In some 12,000 years the pole will pass within 5° of *Lyra*, our zenith star in August, as already noticed. This is the most brilliant and notable star that ever will be, or can be, a pole star. Leaving this beautiful star behind, as others have been in course, the pole now traverses a desert waste, as it were, with scarcely a dim light to cheer its lonely way for more than 8,000 years, when it approaches very near the memorable star *Alpha Draconis*, associated with the Egyptian Pyramids, and was doubtless the pole star when those monuments of antiquity were built.

The "*Great Pyramid*" has an opening directed to the north and so inclined to the horizon that if the axis of the opening be extended to the heavens, it would meet the great meridian circle of the Pyramid at an altitude of 26° 18', corresponding to the latitude of the place.

Many of the smaller pyramids are found to have similar openings, directed to the same point in the heavens. It is said that out of the nine pyramids still standing at Ghizeh, six of them have such openings.

Now is it found by careful computation, on the basis of precession, that the position of the pole corresponded almost exactly to this point of the heavens, a little more than 4,000 years ago. Let the pole now be continued till it has completed a revolution and stands at its present position, note the number of degrees passed over on the ecliptic, multiplying by 71.6 gives 4150 years, subtracting the present era (1876) gives 2274 years before Christ, which agrees very nearly with the best authorities as to the date of the Pyramids.

In like manner the rising and setting of certain stars, or clusters of stars, at a particular season of the year, is very different now from what it was in past ages, or will be in ages to come.

If the rising or setting of a star with the sun at a particular season has been recorded by the ancient Husbandman, Poet, or Philosopher,—admitting the observations to be correct, we have a sure method of ascertaining the time in which the observer lived.—thus Hesiod informs us that Arcturus rose, in his time, 60 days after the winter solstice, but now Arcturus rises acronically a little more than 40 days later in the same latitude, making about 39 degrees passed over by Precession since that time.*

To illustrate this,—turn the key of the apparatus backwards till the vernal equinox has passed over 39° on the ecliptic, reaching the ninth degree of the constellation Aries.

Now the instrument shows the condition of things at the time of Hesiod,—the distance of the north pole from the present north star,—the position of the Equinoxes and Solstices, and the changes which the signs have all made with regard to the constellations of the Zodiac, while the rising and setting of all the stars in the same latitude of Arcturus have been equally affected by Precession. Now reckoning 71.6 years to a degree, as before, we obtain $39.4 \times 71.6 = 2821$ years since the time this Poet lived. Subtracting the present era (1876), gives 945 years before Christ.

Astronomy thus becomes the direct hand-maid of Chronology.

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*$365\frac{1}{4} : 40 :: 160° : 39.4$ degrees.

Friendly Commendation.

From PROF. ALDEN of the Worcester Technical Institute.

WORCESTER, Aug. 23d, 1876.

The young student of Astronomy often finds it difficult to hold in his imagination all the planes, circles and points in the heavens, the names of which have become entirely familiar to him; and especially to preserve their proper relations during those motions of the earth which produce important results, such as change of seasons, precession, &c.

From a personal observation of the working of Prof. Bushee's ingenius Instrument, I am convinced that it will prove of practical value to teachers and pupils, by the clearness with which it brings out these and the many other points which it was designed to illustrate. From its size and style of mounting, it can be successfully used before large classes.

GEORGE I. ALDEN,
Prof. of Applied Mechanics,
Worcester Free Institute.

From A. P. MARBLE, Esq., Superintendent of Public Schools of the City of Worcester, Mass.

Office of Superintendent of Public Schools,
WORCESTER, MASS., Aug. 24, 1876.

I have examined Prof. Bushee's PRECESSION APPARATUS with care. It seems to me admirably adapted to illustrate the motion of the pole and the changes that take place in the "Great Year." For explaining to pupils the difference between Right Ascension and Celestial Latitude it is unsurpassed by any apparatus I have ever seen. I consider it a necessity for every class in advanced Astronomy.

A. P. MARBLE, Supt. of Schools.

Size and Style of Construction of the

PRECESSION APPARATUS.

The Pattern Instrument already constructed, as seen in the engraving, is of large size, adapted to Colleges, Academies and High Schools, the outer circles being from 15 to 18 inches in diameter, so that they can be easily seen by large classes in the lecture room. See cover and page 15.

All the Instruments will be made after the general pattern and in the most thorough and substantial manner, every part,—except the tall heavy stand,—of solid cast brass, turned and polished, and all the working parts, as a whole, firmly mounted for table or floor, making an elegant piece of apparatus for a collection outside of its scientific or educational value.

Another form of Mounting.—It may be often preferable to use a tall heavy stand for the floor with movable joint, in order to give the apparatus any desired angle to the horizon, corresponding to the latitude of the place, with an independent circle to represent the horizon so suspended upon the ecliptic in regard to centre of gravity, that it always retains its horizontal position, whatever angle the ecliptic may make with it, as shown in Frontispiece.

Arrangements are made to manufacture, to order, the large size Apparatus, at a cost as low as can be afforded for that style of Instruments.

A System of Questions and Problems for exercise will soon be published to accompany the Apparatus.